

MASTER THESIS

**Designing, developing and testing an eDNA  
sampling payload system with winch capabilities  
for Unmanned Aerial Vehicles (UAVs)**

Creation of sampling attachment for aerial drone.

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## **Abstract**

This master's thesis focuses on advancing the development of a Drone assisted Environmental DNA (eDNA) testing system, a relatively new approach to enhancing precision and efficiency in biodiversity monitoring. This approach will significantly simplify the sample collection process, reducing the need for manual intervention. The goal of this master's thesis was to develop concepts and then to prototype it into a robust near-prerelease product. The scope of this thesis involved extensive RD to develop an eDNA sampling payload system with a winch which lowers the sampling equipment 5m below the surface of the water. The emphasis was to develop a water floating payload and to reduce the payload weight to better enable the drone to carry the sampling apparatus more easily and efficiently. This included material selection and structural optimization to obtain a lighter, yet robust design. The addition of functional components with a winch system was important to control the descent and recovery of the water sampling device. An Arduino-based control system was integrated in the design, managing the electronic components housed within the payload. This upgrade aimed to automate the sampling process and provide easier remote access to the payload.

This master's thesis project discusses how the prototype was developed from concept to a complete functional, aesthetic product for field testing with potential for commercial application. The progress made in payload design, and functional components marks a leap towards a more capable and user-friendly eDNA testing approach that can positively impact biodiversity monitoring and environmental studies.

## **Acknowledgements**

We would like to take the opportunity to thank EDNA flights for Biodiversity and our supervisor Arion Pons for all the help and guidance throughout this project. We are also grateful for the collaboration with EDNA flights and how they have been trusting our process and decisions throughout the duration of the project.

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# 1

## Introduction

### 1.1 Background

Environmental DNA (eDNA) sampling is a method for detecting organisms in ecosystems by analyzing DNA fragments found in the environment. Water sample collection is a key step, with methods tailored to site accessibility. Samples are collected directly with handheld buckets when sites are accessible, from a boat for areas farther from shore, or using a bucket attached to a rope as a last resort. The collected water is filtered manually or using an electric screwdriver-adapted pump to simplify the process. Filters are dried, treated with alcohol to remove moisture, and frozen to stabilize the DNA before being sent to labs for analysis. Maintaining sterility at all stages is critical to prevent contamination and ensure reliable results. This streamlined process integrates practical field methods with precise laboratory analysis to monitor biodiversity effectively.

Harsh cleaning requirements or the need for fresh equipment per sample can complicate fieldwork, making the process time-consuming and labor-intensive. To address the challenges of maintaining sterility and handling complicated cleaning protocols, we wanted to automate eDNA sampling process using a drone payload designed specifically for this task. By integrating a drone with a sampling payload, we aim to streamline the collection process while ensuring sterility. The drone will enable efficient sampling in hard-to-reach locations, reduce human intervention, and eliminate the difficulties associated with handling industrial cleaning equipment. This solution will enhance the reliability of eDNA sampling, paving the way for more efficient biodiversity monitoring.

### 1.2 Company background

EDNA flights, a consulting firm based in Västerås specializes in environmental mapping through the use of aerial drones, as well as the collection of terrestrial and aquatic samples. With a focus on serving DNA labs, they provide eDNA samples that involve a unique water sampling method. They extract water from the testing site, passing it through a filter specifically designed to capture DNA, which is then sent to the lab for analysis. The choice of filter varies based on the water's purity. Alcohol is then passed through the filter to remove the water and isolate the DNA. The filters are frozen and sent to a lab for analysis. Since its founding in 2021, EDNA flights has grown to three employees.

### **1.3 Overview of report**

The report contains an overview of the methods and processes followed during the collaboration with specific requirements. The development process has the conceptualization phase where numerous design concepts and solutions were created and explored. These ideas were subsequently pitched to EDNA Flights for evaluation and feedback. The possible methods of making physical prototypes were one of the key considerations in ensuring that the selected designs were able to be implemented with resources, tools, and materials already accessible. This approach helped with development speed and avoided any unnecessary complexities during the prototyping phase.

The report focuses on the completed CAD (Computer-Aided Design) model. The CAD model give the opportunity for refinements to the payload and assists in design for manufacturability. Integrated with the payload, considerable effort was spent on the design and fabrication of a winch system. The winch is the key component in deploying and retrieving the sampling tool. Additive manufacturing (3D printing) was used as the main prototyping method. This manufacturing approach enabled rapid iteration, the ability to produce low-quantity complex parts and therefore allowed for faster validation cycles.

The report also investigates the incorporation of IoT (Internet of Things) and electronics in the target payload, the issues faced with Arduino boards have been discussed. The next section of the report provides an overview of the development and analysis of the project prototypes to address technical issues and discover solutions.

Lastly, the report outlines recommendations for additional work on the final prototype. Also, there are recommendations that can improve the product and feature updates for the next generation of EDNA payloads.

# 2

## Design specifications

### 2.1 Overview of the previous project prototype

The earlier prototype developed during the first year of the master's program as a part of the product development project served as foundation for the developments made in the thesis project. The components of this prototype are illustrated in Figure 2.1. It was a relatively simple design. The central structure was a 3D-printed box designed to house and secure all the internal components. This box featured a lid that provided basic water resistance.

Inside the box, the main components included a friction contact system, a motor, a battery, and a receiver. The receiver was wirelessly connected to a remote control, allowing the operator to manage both the winch and pump systems. The design aimed to offer a compact and functional solution for the deployment and retrieval of payloads. Mounted underneath the box was a winch, to lower and retrieve the payload as needed. Attached to the winch system was a pump, which was connected to a short pipe and a filter. This configuration allowed for efficient water sampling.

The remote control served as the primary interface for the operator, enabling precise control over the winch and pump systems. While the prototype achieved basic functionality, it highlighted several areas that required improvement, such as water resistance, Aesthetics, weight of payload etc. These learnings directly influenced decisions implemented in the thesis project.



**Figure 2.1:** An exploded view of all the components from SAM version 1



**Figure 2.2:** A picture of SAM version 1, being deployed

## 2.2 Master thesis Project requirements

The requirements for the master thesis project were provided by the company. These requirements were discussed with our examiner to evaluate their feasibility and ensure they could be achieved within the scope of the project. The key requirements were as follows,

**Lightweight Design:** The system, referred to as SAM, was required to have a total weight below 2 kilograms.

**Protection for Electronics:** All electronic components had to be securely housed in a compartment to minimize any damage caused by exposure to water.

**Waterproof Body:** The body of SAM needed to be waterproof, not only to enable safe operations in aquatic environments but also to prevent long-term degradation of the prototype body.

**Aesthetic and Visual Appeal:** The design had to be visually appealing and well-structured, maintaining a professional and polished appearance while being functional.

**Range and Connectivity of IoT System:** The IoT system integrated within the design had to maintain a reliable range and connectivity to enable smooth communication and control of the system during operation.

These requirements served as the foundation for the project and guided the design, prototyping, and testing processes throughout the development cycle.

## 2.3 Method for product development

This project used the Agile product development approach, which proved to be very effective. The Agile method allowed the team to revisit and revise their plans whenever they faced challenges or obstacles that made it difficult to move forward. This approach emphasized breaking the work into smaller, manageable stages, called iterations, and encouraged the team to continuously evaluate and improve their ideas throughout the project.

One of the key benefits of Agile was the focus on teamwork and collaboration. By working closely together and sharing ideas, the team was able to address problems quickly and make necessary changes to stay on track. This approach also supported flexibility, allowing the team to adapt to any new requirements or changes without disrupting the overall progress. Agile not only helped speed up the development process but also ensured that the final outcome was aligned with the project's goals.

## 2.4 Concept elimination

During the initial stages of the project, multiple concepts were generated to explore possible solutions. However, some of these concepts were deemed unfeasible, hence, discarded.

Firstly, if a concept failed to convince our company, it was immediately scrapped. The supervisor's feedback played a crucial role in determining the viability of each concept. For instance, some concepts, despite being functional, were criticized for being aesthetically unpleasing. Since aesthetics was a key requirement for the project,

Such concepts were not considered further.

Secondly, manufacturability played a significant role in evaluating the concepts. As the project relied on additive manufacturing, particularly 3D printing, any concept that could not be easily manufactured was eliminated. For example, if a part's size (in actual scale) exceeded the build volume, it was discarded right away. Scaling down a part for printability was not an option here

# 3

## Product Concept

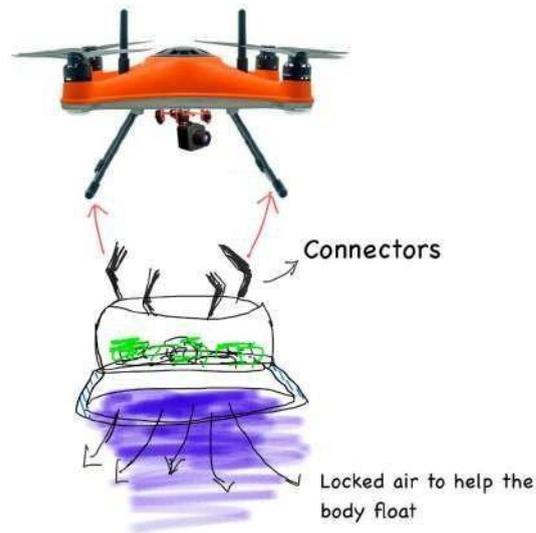
### 3.1 Concept generation

Initially, our first product included a variety of design concepts, each with different characteristics regarding stability, energy efficiency, and sampling effectiveness. The step of concept generation resulted in many different ideas, but only a few showed potentials. However, after an additional assessment of the theoretical feasibility of each concept, only a small subset was deemed practical, with multiple ideas discarded prior to prototyping.

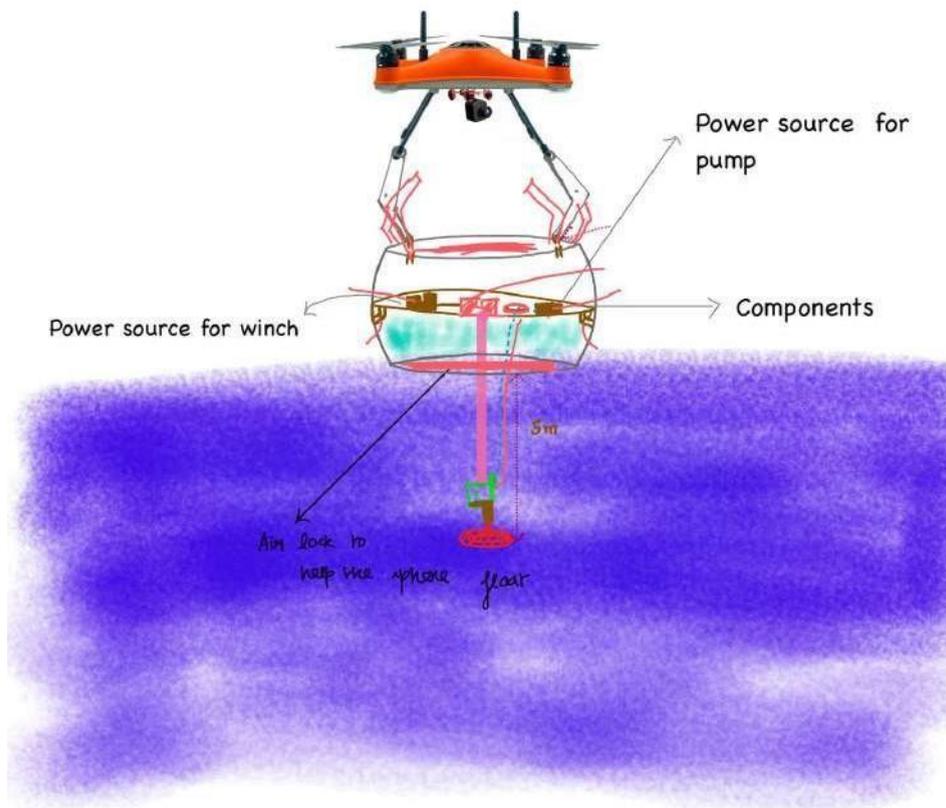
#### 3.1.1 Concept 1: Hollow body

The first concept involved directly attaching the payload body to the legs of the drone. This design featured a hollow underside, intended to create a vacuum effect between the payload and the water's surface. The vacuum effect was theorized to provide a stabilizing force, potentially allowing the payload to stay anchored to the water surface during sampling operations with entrapped air

The electronic components would be housed on a central midplate, at a specific height within the payload to shield them from water exposure. A winch mechanism was envisioned as the core of the sampling process, allowing a tether to lower and retrieve samples from specific depths. This concept aims to reduce the power consumption of the drone by letting it land on water while being mounted to the payload. By doing this, the drone can get some stand by time and can conserve battery usage since the drone would need to collect multiple samples across various points within a water body, conserving power was critical for enabling efficient and extended sampling operations. Figure 2.2 is an alternative version of concept 1 with minor changes to the design of the body



**Figure 3.1:** Sketch of the Hollow body concept. The midplate encompasses the electronic components



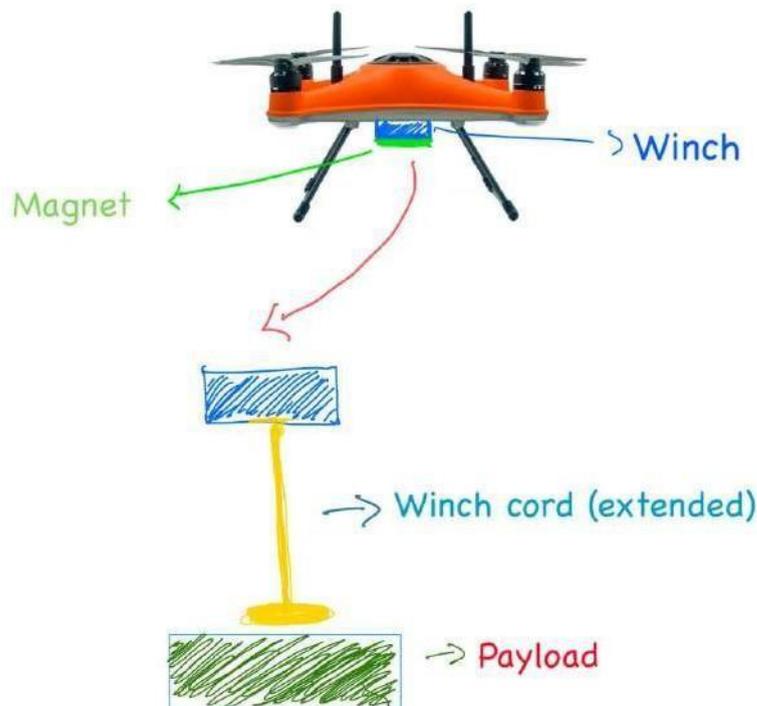
**Figure 3.2:** Hollow hemispherical body (Alternative version for concept 1)

### 3.1.2 Challenges with concepts 1

The challenges that led to eliminating this concept centered around its elevation from the water surface due to the necessary connectors between the payload body and the drone's legs. This elevation made the system vulnerable to destabilization by water currents, particularly during sampling. Strong currents could exert a risk of movement or tipping and impacting sampling accuracy. The design Aesthetic did not convince the company. These considerations ultimately led to the decision to eliminate this concept before moving forward to prototyping.

### 3.1.3 Concept 2: Flat Magnetic Plate with Winch Mechanism

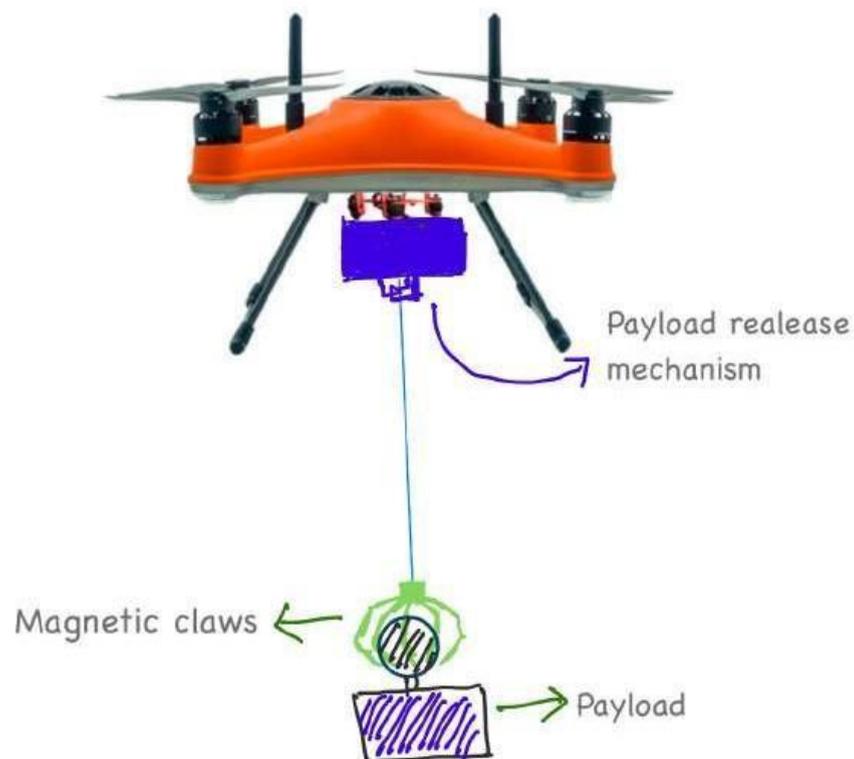
This concept involved integrating a flat magnetic plate with a winch to facilitate the deployment and retrieval of the payload. The payload was theorized to have a metal plate screwed to the top surface. The process begins with the drone positioning itself above the designated sampling area. The winch would then lower the payload, equipped with the magnetic plate, onto the water surface. There is a chance of the payload getting taken away in the water current but, magnetic plate would secure the payload during the sampling operation, which typically lasted between 5 to 10 minutes. Upon completion, the winch would retract, lifting the payload back to the drone for transportation to the next sampling site. This approach aimed to streamline the sampling process by utilizing magnetic force for secure attachment, thereby reducing the need for complex mechanical locking mechanisms.



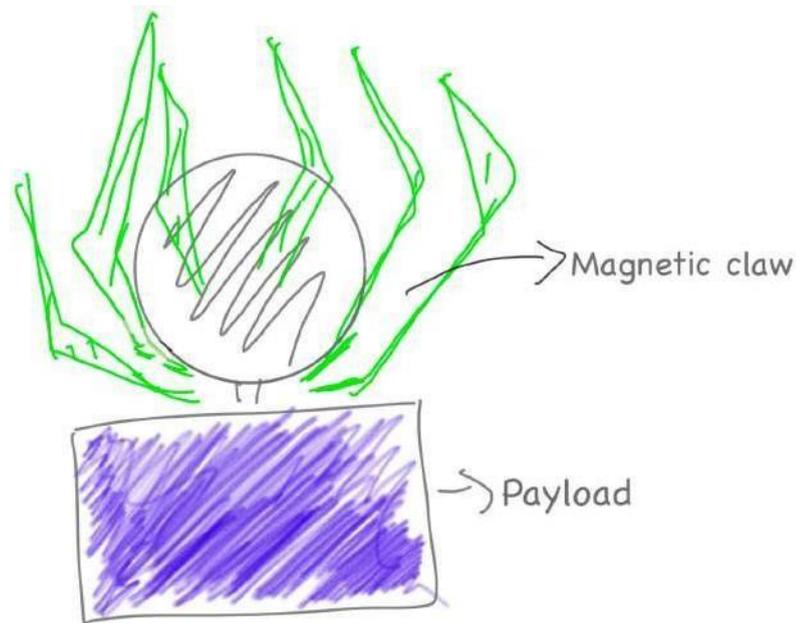
**Figure 3.3:** Magnetic plate with winch mechanism

### 3.1.4 Concept 3: Magnetic Claw

In this concept, a magnetic claw or gripper was proposed to manage the deployment and retrieval of the payload. The claw would be powered by the drone from one of its ports. The drone would hover above the target area and the gripper would release the payload onto the water surface to begin sampling. The magnetic gripper was theorized to maintain a firm hold on the payload during transportation and to release it upon reaching the sampling site. After the sampling process, the gripper would re-engage with the payload, securing it for retrieval and subsequent transport. This concept focuses on providing a controlled method for handling the payload, leveraging magnetic force to ensure reliable grip during flight operations.



**Figure 3.4:** *Magnetic claw*



**Figure 3.5:** *Claw hold*

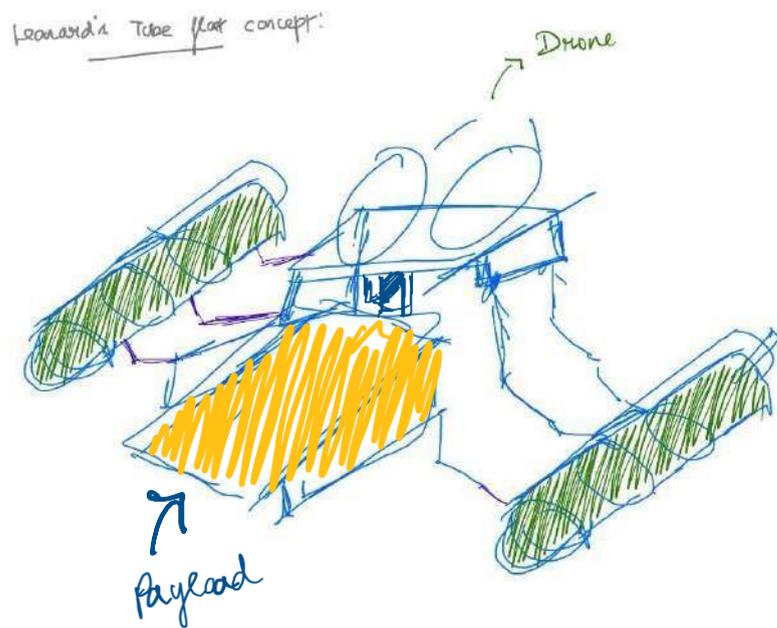
### 3.1.5 Challenges with concepts 2 and 3

Both concepts presented significant challenges. In Concept 2, the necessity for strong magnets, such as neodymium magnets, raised concerns about potential interference with the electronic components within the payload. Moreover, the reliance on two separate subsystems, the drone's winch and the payload's magnetic plate complicated the system, contradicting our desire to have a unified, streamlined design. In Concept 3, the magnetic claw's effectiveness was questioned, particularly under adverse weather conditions. Strong winds could compromise the gripper's hold on the payload, increasing the risk of accidental release during flight. Such an event could result in the payload falling in populated areas, posing safety hazards and potential liability issues. These considerations led to the conclusion that, despite their innovative approaches, both concepts were impractical for reliable and safe payload management in our application.

### 3.1.6 Concept 4: Tubular pontoons

This concept involved attaching tubular pontoons to the drone's legs using custom pontoon holders. The primary objective was to enhance stability during water sampling by providing better buoyancy. A prototype featuring cylindrical pontoons was developed and subjected to a float test under various conditions, including exposure to currents and erratic winds. A tether was attached to the prototype and the other end of the tether was held securely. The pontoons demonstrated satisfactory performance, maintaining stability throughout the tests. However, the design required further optimization to address potential challenges such as increased drag

and the added weight of the pontoons, which could impact the drone's maneuverability



**Figure 3.6:** *prototype concept sketch with Tubular pontoons*

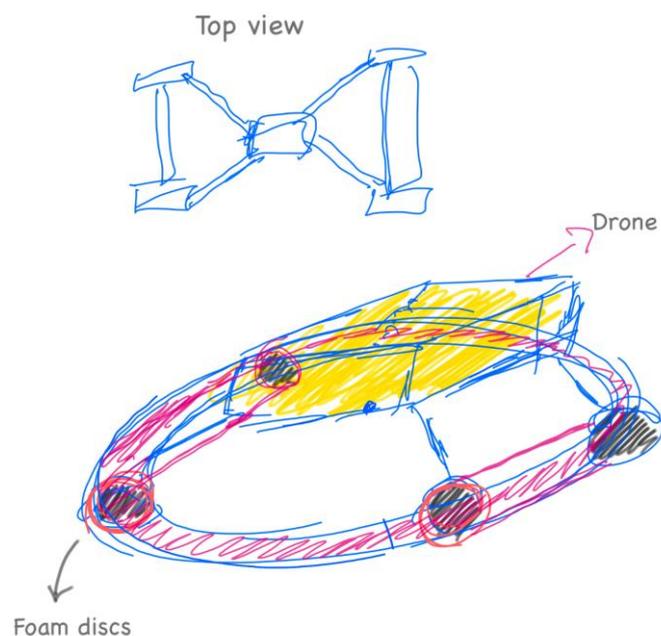


**Figure 3.7:** *Float test with prototype. The test was done at Lund Sea coast with harsh wind conditions - Lund, Sweden. The prototype test is later explained in section 4.2.3*

### 3.1.7 Sub concept 4: Floatable foam discs

One alternative design for concept 4 suggested attaching floatable foam discs to the 3D-printed legs instead of pontoon system, which in turn would be connected to the legs of a drone. This arrangement was theorized to enhance their buoyancy and stability during the sampling process. Some of the problems that could potentially arise with this design could be securing the foam discs properly onto the frame of the drone, and foam discs could lead to uneven flotation with relation to how the components are positioned inside the payload, tilting the drone.

This idea was overlooked because the team wanted to be efficient with time and search for a better solution.



**Figure 3.8:** *Foam discs on legs*

### 3.1.8 Challenges with concept 4

Both concepts presented challenges related to increased drag. This necessitated careful consideration to ensure that the benefits of better stability for the payload during sampling did not compromise the drone's flight.

## 3.2 Concept 5

After reviewing advantages and limitations of the preceding concepts, Concept 5 was designed using CAD software. Concept 5 only came up during the prototyping phase, building upon the success of Concept 4's float test result, this iteration retained the pontoon holders, which had demonstrated good buoyancy. To address the challenge of protecting electronic components from

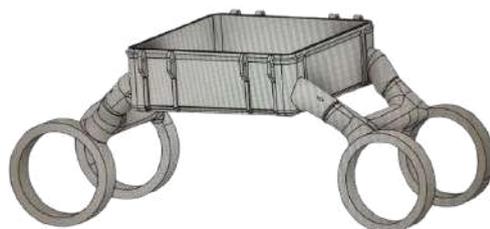
water exposure, a robust, tightly sealed enclosure was introduced. This enclosure was designed to be securely fastened atop the pontoon holders using screws. Concept 5 not only integrated the successful elements of earlier concepts but also presented a good foundation for further optimization in the prototyping phase.



**Figure 3.9:** CAD Design of concept 5 featuring the pontoon holder and the sealed

### 3.3 CAD Design

The prototype, "SAM," developed in Fusion 360, is a modular, lightweight frame designed to contain crucial elements that include electronics and a winch. The design evolved considerably, from an initial type with a lot of moving parts to one with fewer or no moving parts, a clean design with reliability. The decision to optimize the prototype for 3D printing was influenced by design for additive manufacturing (DfAM) principles. Wall thickness, infill density, and draft angles were kept in check and balanced for maximum structural integrity while maintaining a manufacturable model. The result is a viable prototype that meets the key requirements of the project.



**Figure 3.10:** Incomplete Model of SAM on CAD. We used generative AI technique to connect the legs to the body



**Figure 3.11:** *CAD model of SAM*

### 3.4 Winch

The Winch was designed in Fusion 360 to be a compact setup that can be fit inside SAM and also Keeping Robustness and space optimization in mind. The inclusion of gears to the winch was an essential step to increase its load handling capacity



**Figure 3.12:** *Winch CAD model*

### 3.5 IOT and Electronics

Electronics and IoT power and drive the payload to operate and collect the sample. When selecting the electronic components, we were given clear instructions by EDNA Flight to incorporate the MRK Arduino Data Network module. This directive shaped our entire approach to component selection, ensuring good integration and wireless control of the system.

The Arduino module serves as the core controller, managing the operation of a 12V 4000 RPM brushed DC motor. This motor is powered by a 12V lead-acid battery, providing the necessary energy to drive the system. The motor, in turn, powers the

prototype's winch mechanism, enabling the payload's functionality. The integration of the Arduino not only automates the winch system but also allows for remote operation, enhancing the overall versatility and responsiveness of the prototype.

# 4

## Prototyping

Evaluating concepts and ideas often requires more than theoretical tools and subjective analysis. Physical methods, such as prototypes and tests, play a crucial role in providing practical insights and immediate feedback, especially when questions about an idea's functionality cannot be easily resolved by other means. This chapter discusses the role of prototyping and its significance in refining concepts and ensuring their feasibility. The creation and use of prototypes were integral to the iterative process, enabling continuous refinement and improvement. Over the course of the project, prototyping techniques evolved from simple models constructed using readily available materials to more advanced and detailed iterations. These prototypes served as tangible representations of ideas, facilitating experimentation and fostering a deeper understanding of potential challenges and opportunities.

Tests conducted during the prototyping phases helped confirm the practicality and performance of proposed solutions. By iterating between building and experimenting, the project ensured that the concepts developed were both innovative and robust, meeting the objectives effectively.

### 4.1 Additive manufacturing

Additive manufacturing was chosen as the primary method for prototyping and manufacturing in this project to avoid traditional and conventional techniques that often limit design flexibility and efficiency. This approach allowed for the creation of customized geometries that would have been impractical with conventional methods. By utilizing 3D printing, the team could rapidly prototype and refine designs. The process also significantly reduced material waste and production time, making it a sustainable and cost-effective solution. Additive manufacturing proved instrumental in transforming abstract concepts into functional prototypes that aligned with project requirements



**Figure 4.1:** *Prusa printer at work*

## 4.2 Prototypes

The development of the payload involved multiple iterations, each carefully constructed and tested to refine the design. Initially, the prototyping process began by assembling the payload piece by piece, with various components linked together to form the complete structure. However, as testing progressed, it became evident that having a larger number of moving parts negatively impacted on the stability and overall performance of the payload. This realization occurred late in the testing phase, leading the team to rethink the design strategy. The revised approach focused on creating a singular, cohesive body with minimal to no moving parts, thereby enhancing the stability and reliability of the payload. The design was optimized to reduce the need for support structures during printing, which helped preserve the integrity and precision of the final part.

### 4.2.1 Material selection

When it came to selecting the material for the final prototype, the team weighed the options between PLA and PETG. Both materials have their merits, but the decision ultimately favored PLA. Despite PLA's known limitations, such as its susceptibility to degradation in humid environments and its relatively poor performance when exposed to water or fluids over extended periods, it was considered adequate for this application. The key factor in this decision was the nature of the payload, which did not involve significant mechanical loading or long-term exposure to adverse conditions. PLA offered sufficient strength, ease of printing, and dimensional accuracy, making it an ideal choice for the prototype. Furthermore, PLA's ability to meet the specific requirements of the payload body, coupled with its availability and printability, made it a better choice of material for this phase of development.

### 4.2.2 Prototype 1

The first prototype focused on a drone payload attachment system with leg attachments designed to function as pontoon holders. These legs, integrated with the drone, were intended to provide stability and support for the payload. However, early iterations revealed flexibility issues, as the legs lacked the necessary rigidity to maintain stability during operation. This prototype highlighted the importance of balancing structural strength with the functional requirements of the design, serving as a foundation for further refinement in achieving an optimal solution.



**Figure 4.2:** *Prototype 1 in display with some leg concepts*

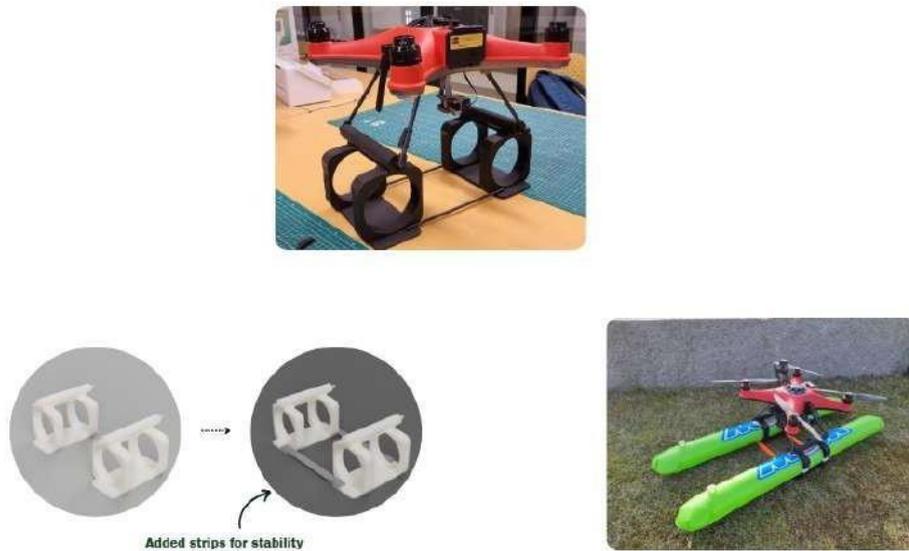
### 4.2.3 Prototype 2

The second prototype introduced several key refinements to the drone's leg attachment system, focusing on resolving the issues of the initial design and improving it. To enhance rigidity, strips were added between the legs, creating a reinforced structure that provided better support for the pontoons and ensured more balanced weight distribution. This adjustment improved the system's structural rigidity, resulting in a more reliable base for the payload to float.

However, while the stability of the design improved, the large surface area of the pontoons introduced a new challenge: excessive drag force during flight. This increased aerodynamic resistance made it difficult for the drone to maneuver efficiently, limiting its ability to perform smooth and precise movements. The combination of improved stability with reduced aerodynamic efficiency highlighted the need for further refinement.

This prototype was tested on the coast of Lund Sea to identify flaws. The test was a float test to verify if the prototype was able to stay afloat whilst shouldering the

Drone. Figure 4.4 illustrates the prototype floating on the water, secured by a tether that the team holds to protect it from strong winds that might drift it away.



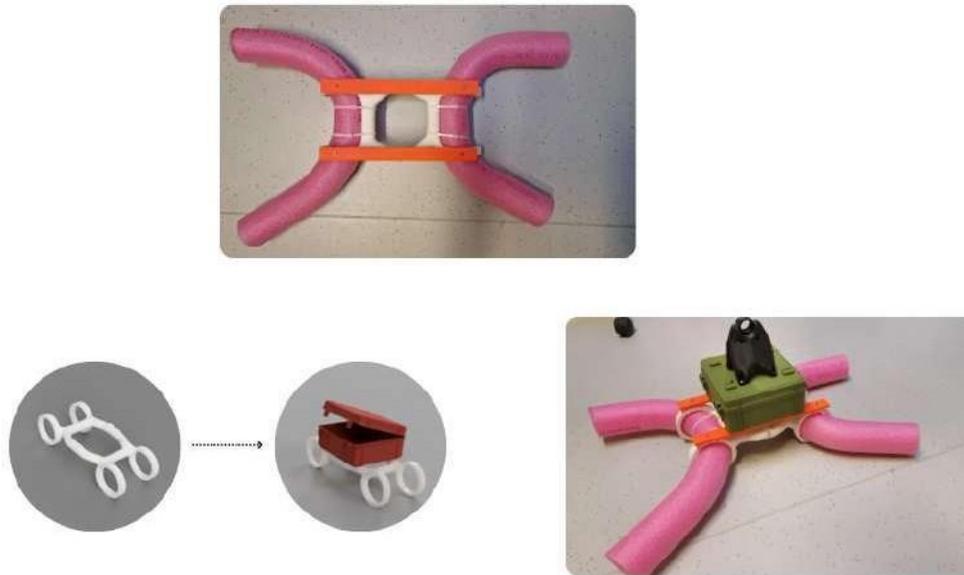
**Figure 4.3:** *Prototype 2 in display with large pontoons*



**Figure 4.4:** *Prototype captured during a test at Lund's Sea coast with harsh winds*

### 4.2.4 Prototype 3

The third prototype introduced further refinements to address the challenges faced in earlier iterations and improve overall performance. The design was scaled down, featuring smaller pool noodles instead of pontoons and shorter legs to reduce drag during flight. Additionally, the payload was mounted on top of the structure, at the center of the structure. We still had room for optimization from here.



**Figure 4.5:** *Prototype 3 in display with a smaller overall package*

## 4.3 Winch Prototype

The winch prototype was constructed using PLA material, showcasing a compact and durable design for efficient operation. It features an integrated gear system, enabling torque capabilities essential for its functionality. The winch is enclosed within a protective housing, ensuring the internal components remain secure and operate properly. Its primary function is to raise and lower the sampling contraption, a separate subsystem that includes a pump and filter designed to collect and process samples.



**Figure 4.6:** *Winch and gears*

## 4.4 Final prototype

The final prototype represented the culmination of the design process, incorporating all previous learnings and refinements into a cohesive and functional system. This iteration featured an aesthetic and lightweight design with the least number of moving parts, better reliability and simplified assembly. The structure was optimized to accommodate all electronic components securely. These improvements ensured that the prototype was efficient, practical, and visually appealing, meeting both functional and design objectives effectively



**Figure 4.7:** *Final prototype in display with fewer moving components*

# 5

## IOT and Electronics

### 5.1 Electronic Components

The payload requires these electronic components that enable the prototype's operation. Each component was chosen for smooth integration, efficient power delivery, and precise control over the system. Below is a breakdown of the key components and their roles:



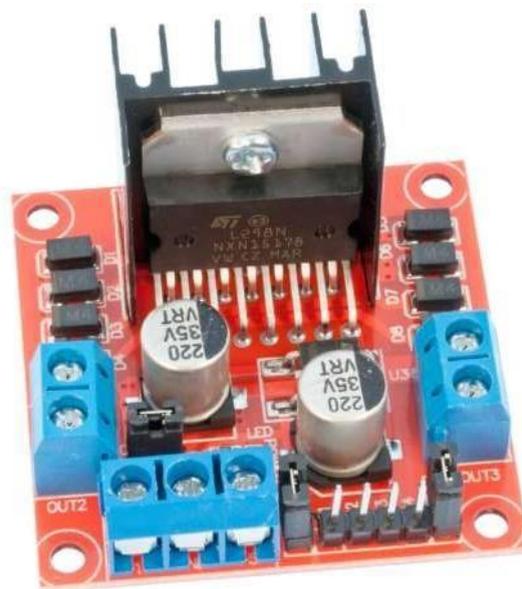
**Figure 5.1:** *12V DC Motor.*

**12V 4000 RPM Brushed DC Motor** The primary actuator in the system is a 12V brushed DC motor capable of reaching 4000 revolutions per minute (RPM). This motor is responsible for driving the prototype's winch mechanism, providing the necessary torque and speed to handle lifting and lowering tasks. The brushed design of the motor ensures cost-effectiveness and simplicity, making it easy to control using standard motor drivers.



**Figure 5.2:** 12V Battery.

12V Lead-Acid Battery To power the motor and the entire electronic system, a 12V lead-acid battery is employed. Lead-acid batteries are known for their reliability, affordability, and ability to deliver high surge currents, which is crucial for driving the motor under load. The battery's capacity ensures extended operation, while its durability allows it to withstand the mechanical demands of the prototype.



**Figure 5.3:** LN298 H-Bridge.

L298 Dual H-Bridge Motor Driver (5-35V, 2A) The L298 motor driver is a dual H-bridge module that allows bidirectional control of the brushed DC motor. It can handle voltages between 5V and 35V and supports currents up to 2A per channel, making it an ideal match for the 12V DC motor. The H-bridge design enables smooth control over motor direction and speed, which is critical for the precise operation of the winch. Additionally, the L298 is robust and provides thermal protection, ensuring reliable performance even under continuous use.



**Figure 5.4:** *Arduino MKR 1400.*

At the heart of the control system lies the Arduino MKR 1400/1500, an IoT-focused development board equipped with cellular connectivity. This module not only serves as the primary controller but also enables remote monitoring and control of the prototype. By integrating the MRK data module, the system gains the ability to receive and process commands wirelessly, significantly enhancing its flexibility and scalability. The Arduino interfaces with the L298 motor driver, allowing precise motor control based on sensor inputs or remote commands.



**Figure 5.5:** *System Integration.*

System Integration The integration of these components forms a cohesive system

where the Arduino acts as the central hub, processing data and issuing control signals to the motor driver. The L298, in turn, regulates the power supplied to the 12V brushed motor from the lead-acid battery, driving the winch mechanism efficiently. This setup ensures that the prototype operates smoothly, whether controlled manually or through remote IoT-based interfaces.

## 5.2 IOT

Arduino IoT Cloud is an easy-to-use platform that allows users to connect, monitor, and control devices remotely. When paired with the Arduino MKR GSM 1400, it enables IoT projects with cellular connectivity, making it ideal for remote monitoring and automation. The IoT Cloud simplifies coding, offers real-time data visualization, and supports secure communication, helping developers quickly build and deploy smart, connected systems. The Arduino MKR GSM 1400 is a powerful microcontroller board designed for IoT (Internet of Things) applications, enabling cellular connectivity through GSM networks. It allows devices to collect and transmit data remotely, making it ideal for projects that require long-range communication, such as environmental monitoring, asset tracking, and smart agriculture.

By integrating with the Arduino IoT Cloud, the MKR GSM 1400 simplifies the process of coding and deploying IoT solutions. The IoT Cloud provides an intuitive platform to design dashboards, monitor devices in real-time, and automate actions based on sensor inputs. Using simple drag-and-drop widgets and Arduino sketches, users can quickly build and manage IoT systems without extensive programming knowledge. This integration makes the Arduino MKR GSM 1400 a versatile tool for both beginners and experienced developers in the IoT space. Now to be able to operate the entire payload system we need a code, the main function of the code is to rotate the motor clockwise so the winch wire reaches a length of 5 meters and then there is a waiting period to collect the EDNA sample and then rotate the winch anticlockwise to retract back the wire which concludes the sampling process

## 5.3 Payload System Operation and Control Code Design

The efficient collection of Environmental DNA (eDNA) samples in marine or terrestrial environments require precise control over the payload system. The payload system consists of a motorized winch mechanism responsible for deploying and retracting a collection device via a wire. To ensure reliable and repeatable sampling, the motor must be programmed to operate in a controlled sequence, allowing the collection device to reach the desired depth or length and remain stationary for an adequate period before retrieval. This document outlines the functional design and control logic of the code responsible for managing the motor and winch system to achieve smooth sample collection.

The following steps detail the sequential operation of the payload system:

- **Initialization:** The system initializes by confirming motor readiness and ensuring the wire is at the starting position.
- **Deployment Phase:** The motor engages, rotating in the clockwise direction. The winch unwinds the wire, gradually lowering the collection device.
- **Sample Collection Phase:** Upon reaching the target length, the motor halts. The system enters a waiting state for a pre-defined duration, typically calibrated based on environmental conditions and the nature of the sample. During this time, the collection device remains stationary, allowing for optimal eDNA accumulation.
- **Retraction Phase:** Following the waiting period, the motor reverses direction, rotating anticlockwise. The winch rewinds the wire, raising the collection device back to the initial position.
- **Completion and Reset:** Once the collection device is fully retracted, the motor stops. The system is ready for subsequent sampling cycles.

Code Design and Implementation The control code governing this process is structured to ensure precision and reliability. Key aspects of the code design include:

- **Motor Control:** Pulse Width Modulation (PWM) signals manage motor speed and Direction.
- **Timing Mechanism:** Timers regulate the waiting period during the collection phase.

## 5.4 Arduino Code for Motor Control

```
//Include the thing properties header file#include
"thingProperties.h"

// Define the motor control pins
#define IN1 14 // Assuming this is one of the motor control pins #define IN2
13 // Assuming this is one of the motor control pins #define ENB 9

void setup () {
  // Initialize serial and wait for port to open:Serial.
  begin (9600);
  // This delay gives the chance to wait for a Serial Monitor delay (15
  00);

  // Defined in thingProperties.hinit
  Properties ();

  // Connect to Arduino IoT Cloud
  ArduinoCloud .begin ( Arduino IoTPreferred Connection );
```

```
// Set the motor control pins as outputs
pinMode ( IN1, OUTPUT);
pinMode(IN2, OUTPUT);
pinMode(ENB, OUTPUT);

// Start with motor off
digitalWrite(IN1, LOW); digitalWrite(IN2, LOW);
analogWrite (ENB, 0); // Motor speed 0

// Set the debug message level and print debug info set
Debug Message Level ( 2);
ArduinoCloud .print Debug Info ();
}

void loop () {
  ArduinoCloud .update ();

  // Control motor based on motorState if (
  motor State ) {
    // Set motor direction forward
    digitalWrite(IN1, HIGH);
    digitalWrite(IN2, LOW);

    // Gradually increase motor speed
    for (int speed = 0; speed <= 255; speed += 5) {analogWrite
      (ENB, speed );
      delay (50);
    }
    delay (10000); // Run motor at full speed for 10 seconds

    // Gradually decrease motor speed
    for (int speed = 255; speed >= 0; speed -= 5) {analogWrite
      (ENB, speed );
      delay (50);
    }

    delay (60000); // Wait for 60 seconds

    // Change motor direction to reversed
    digitalWrite(IN1, LOW);
    digitalWrite(IN2, HIGH);

    // Gradually increase motor speed
```

```

    for (int speed = 0; speed <= 255; speed += 5) {analog Write
      (ENB, speed );
      delay (50);
    }

    delay (10 000); // Run motor at          full   speed for 10 seconds

    // Gradually decrease motor speed
    for (int speed = 255; speed >= 0; speed -= 5) {analog Write
      (ENB, speed );
      delay (50);
    }

    delay (2000); // Wait for 2 seconds
  } else {
    // Turn off the motor
    digitalWrite(IN1, LOW); digita
    lWrite(IN2, LOW);
    analogWrite (ENB,    0); // Motor speed 0
  }
}

void onMotorStateChange () { if (
  motor State ) {
  Serial.println("Motor turned ON");
} else {
  Serial.println("Motor turned OFF");
}
}

```

This code is designed to control a DC motor using an Arduino board, allowing for precise control of speed, direction, and gradual acceleration or deceleration. It integrates with the Arduino IoT Cloud, enabling remote monitoring and control of the motor's state.

In the `setup()` function, the motor control pins are initialized. The pins IN1 and IN2 control the motor's direction, while ENB is a Pulse Width Modulation (PWM) pin used to regulate the motor's speed. These pins are set as outputs to interact with the motor driver. Serial communication is initialized at a rate of 9600 for debugging purposes, allowing real-time monitoring through the Serial Monitor. A delay of 1500 milliseconds ensures the system is ready before proceeding, especially useful when waiting for the Serial Monitor to connect. The `Properties()` function sets up the cloud-related properties. The program then connects to the Arduino IoT Cloud using `ArduinoCloud.begin()`, enabling the motor state (`motorState`) to be controlled remotely. Initially, the motor is set to an "off" state by setting both direction pins (IN1, IN2) to LOW and the speed pin (ENB) to 0.

The `loop()` function is where the motor's operation is handled. The `ArduinoCloud.update()`

function ensures that the cloud connection is maintained, allowing for real-time updates to the motorState variable. If motorState is true, the motor is activated, and a sequence of operations begins. First, the motor is set to a forward direction by setting IN1 to HIGH and IN2 to LOW. The speed is gradually increased from 0 to 255 (maximum speed) in steps of 5 using the PWM signal on the ENB pin. A delay of 50 milliseconds between each increment ensures smooth acceleration. Once the motor reaches full speed, it runs for 10 seconds before gradually decelerating back to 0. This controlled acceleration and deceleration reduce mechanical strain on the motor.

The motor switches to reverse direction by setting IN1 to LOW and IN2 to HIGH. The same process of gradual acceleration to full speed, running for 10 seconds, and deceleration is repeated. Finally, the motor pauses for 60 seconds before the sequence restarts. If motor State is false, the motor is immediately turned off by setting both IN1 and IN2 to LOW and setting the PWM signal on ENB to 0, ensuring no movement.

The program is integrated with the Arduino IoT Cloud, which allows the motorState variable to be controlled remotely. Whenever the motor state changes (from OFF to ON or vice versa), the onMotorStateChange() function is triggered. This function outputs a message to the Serial Monitor, notifying the user of the change in the motor's status. This feature is particularly useful for debugging and monitoring the system's behavior in real time.

In summary, this code demonstrates a comprehensive approach to motor control, combining hardware functionality, software logic, and IoT integration to create a versatile and user-friendly system for controlling a DC motor.

## 5.5 Unstable Operation in Arduino MKR 1400/1500 Boards

During the development and testing phase of the electronic system, significant inconsistencies were observed with the Arduino MKR 1400 and MKR GSM 1500 boards. These inconsistencies directly affected the execution of critical tasks and the reliability of cloud-based control mechanisms. The Arduino MKR 1400 board exhibited unstable behavior during the testing phase. The primary issue encountered was the board's inability to reliably come online, rendering it inaccessible for cloud software control. Despite multiple troubleshooting efforts, the board failed to consistently establish connectivity. However, during isolated instances, the board successfully connected, allowing for the completion of one full test cycle. This test provided limited but valuable insight into the system's functionality under ideal conditions.

To address the connectivity issues with the MKR 1400, the team transitioned to the Arduino MKR GSM 1500 board. Despite extensive troubleshooting and weeks of dedicated testing, the MKR GSM 1500 board consistently failed to come online. This persistent issue prevented any form of successful system integration or cloud control during the testing period.

Due to company resource constraints, obtaining a replacement board was not feasible. As a result, the project team proceeded with system integration and demonstration without the Arduino component. The absence of an operational Arduino board limited the scope of the demonstration and highlighted the critical nature of reliable hardware in future phases of development.

# 6

## Conclusion

### 6.1 Results and outcomes

- The team successfully managed to keep the weight of the payload, including all electronics, under the 2kg threshold, meeting an important project requirement. We had a total weight of 1.7kg (Refer figure 6.2)
- An aesthetically pleasing prototype was created, combining both functionality and visual appeal (Refer figure 6.2)
- Electronics are adequately protected against mild water currents and splashes, but exposure to harsh currents poses a risk. A small gap around the winch spindle drill hole in the payload casing could allow water to seep in, potentially damaging the electronics. This risk can be mitigated by choosing strategic locations for sampling (Refer figure 6.2)
- Waterproofing the payload body was a key requirement, and the team successfully built the prototype using PLA. Despite exposure to float tests, the material showed no significant degradation in color or swelling and demonstrated sufficient water resistance for a prototype-level product and short-term use. While PLA may not withstand long-term exposure, it proved adequate for the SAM prototype. However, the final product will be 3D printed with carbon fiber, as discussed with the company (Refer figure 6.2)

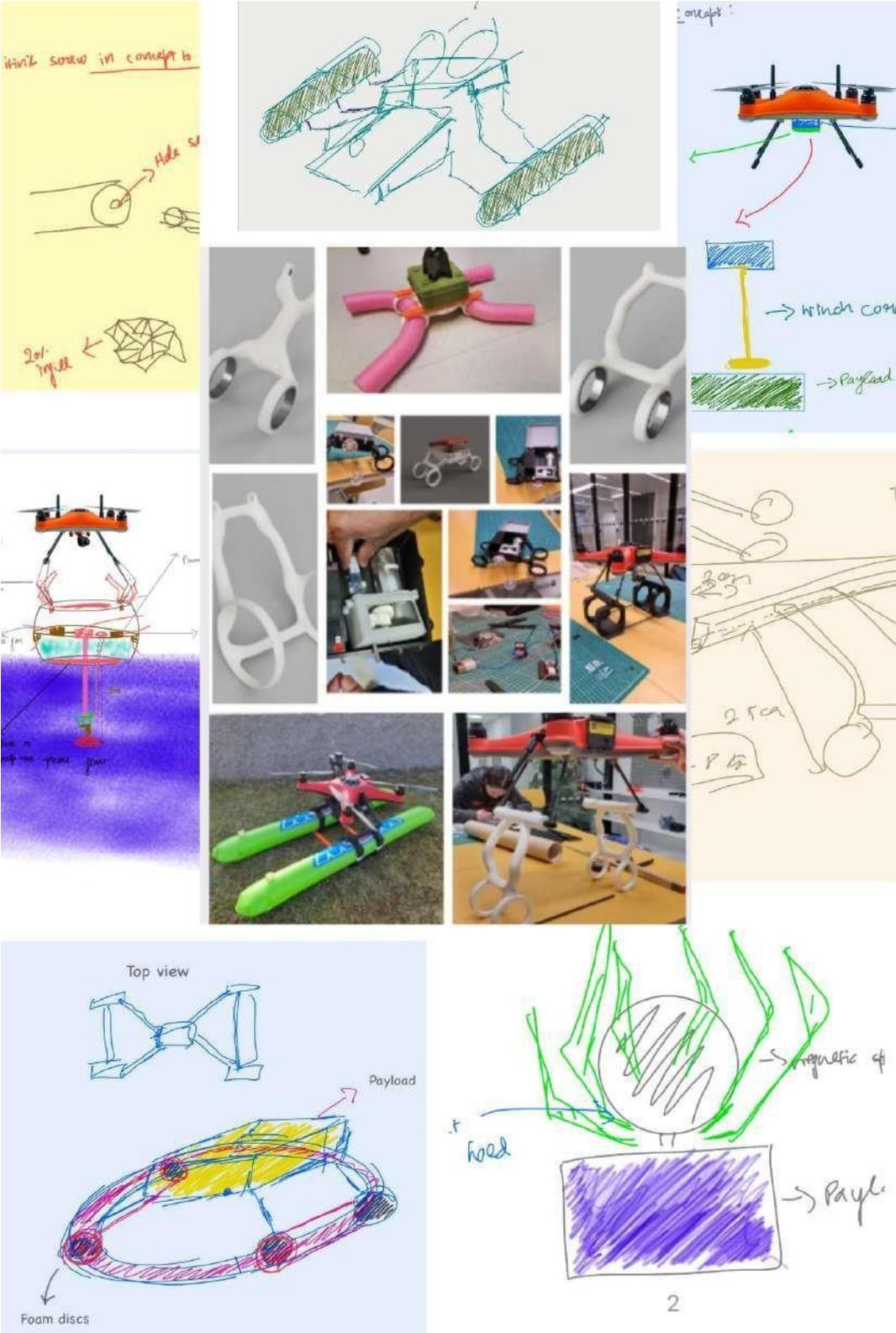


Figure 6.1: Collage of workflow from concept phase to the prototyping phase



**Figure 6.2:** Collage of output achieved from the workflow in the project

## 6.2 Recommendation and Further development

Based on our work, several recommendations have been made to improve performance and efficiency to ensure the effectiveness of the current prototype. By converting the sampling system into a body made of carbon fiber, we can achieve significant weight reduction and enhanced strength and durability, leading to better environmental stress resistance. Changes to the flotation include a better foam material for the pontoons so that the system can better float and stabilize in the water while doing work in a troublesome environment. Making components even more compact will be optimal for their respective assembly, leading to an overall weight reduction, thus improving both maneuverability and operational endurance. The use of an advanced Raspberry Pi board for computation

and system integration where it is needed, adding a receiver in a radio for communication between subsystems to improve reliability and accuracy of actions. Furthermore, updating the design of the winch system, including its gear mechanism, materials, etc., would help optimize its function for raising and lowering the sampling contraption, in any, sliding it as they are raised or lowered. So, following these suggestions will lead to an effective design for efficient, durable, and functional usage, making progress towards a reliable field solution for eDNA sampling

# AI Usage

In our thesis report, we have responsibly utilized AI tools to enhance the quality and efficiency of our work, adhering to the outlined ethical guidelines from Chalmers University Of Technology. AI was primarily used for tasks such as generating initial drafts, refining text, and providing code suggestions, ensuring that all outputs were critically reviewed and validated for accuracy and relevance. Additionally, we employed AI for literature review assistance and data analysis, carefully cross-referencing AI-generated insights with credible academic sources. The extent of AI usage has been transparently documented, with appropriate citations for AI contributions, ensuring academic honesty. Sensitive or proprietary information was not shared with AI tools, and all activities were conducted in consultation with our supervisor to uphold ethical and privacy standards.

# References

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- iii. Adedotun D. Banjo, Vinamra Agrawal, Maria L. Auad, Asha-Dee N. Celestine. Moisture-induced changes in the mechanical behavior of 3D printed polymers. *Composites Part C: Open Access*, Volume 7, 2022, Article 100243. DOI: 10.1016/j.jcomc.2022.100243.
- iv. Chat GPT was used to help with Arduino cloud Code development, which was also used in Arduino IDE software